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Couch

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(54) **METHODS AND APPARATUSES FOR DIRECT DIGITAL DRIVE OF A LASER IN A PASSIVE OPTICAL NETWORK**

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(51) **Int. Cl.**[7] **H01S 3/00**

(52) **U.S. Cl.** **372/38.02**; 372/38.1

(58) **Field of Search** 372/38.1–38.02, 372/38.04

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,046,995 A * 9/1977 Salley 365/127
4,509,130 A * 4/1985 Menzies et al. 700/299
5,299,211 A * 3/1994 Berndt et al. 372/94
5,390,019 A * 2/1995 Fritze et al. 356/459
5,489,981 A * 2/1996 Killpatrick et al. 356/459
5,579,328 A * 11/1996 Habel et al. 372/31
5,604,757 A * 2/1997 Liang et al. 372/38.04
6,118,828 A * 9/2000 Schleifer 375/317
6,201,288 B1 * 3/2001 Iwasaki et al. 257/528
6,389,046 B1 * 5/2002 Stayt et al. 372/29.02
6,504,634 B1 * 1/2003 Chan et al. 398/129
6,707,833 B1 * 3/2004 Kimbrough 372/38.02

* cited by examiner

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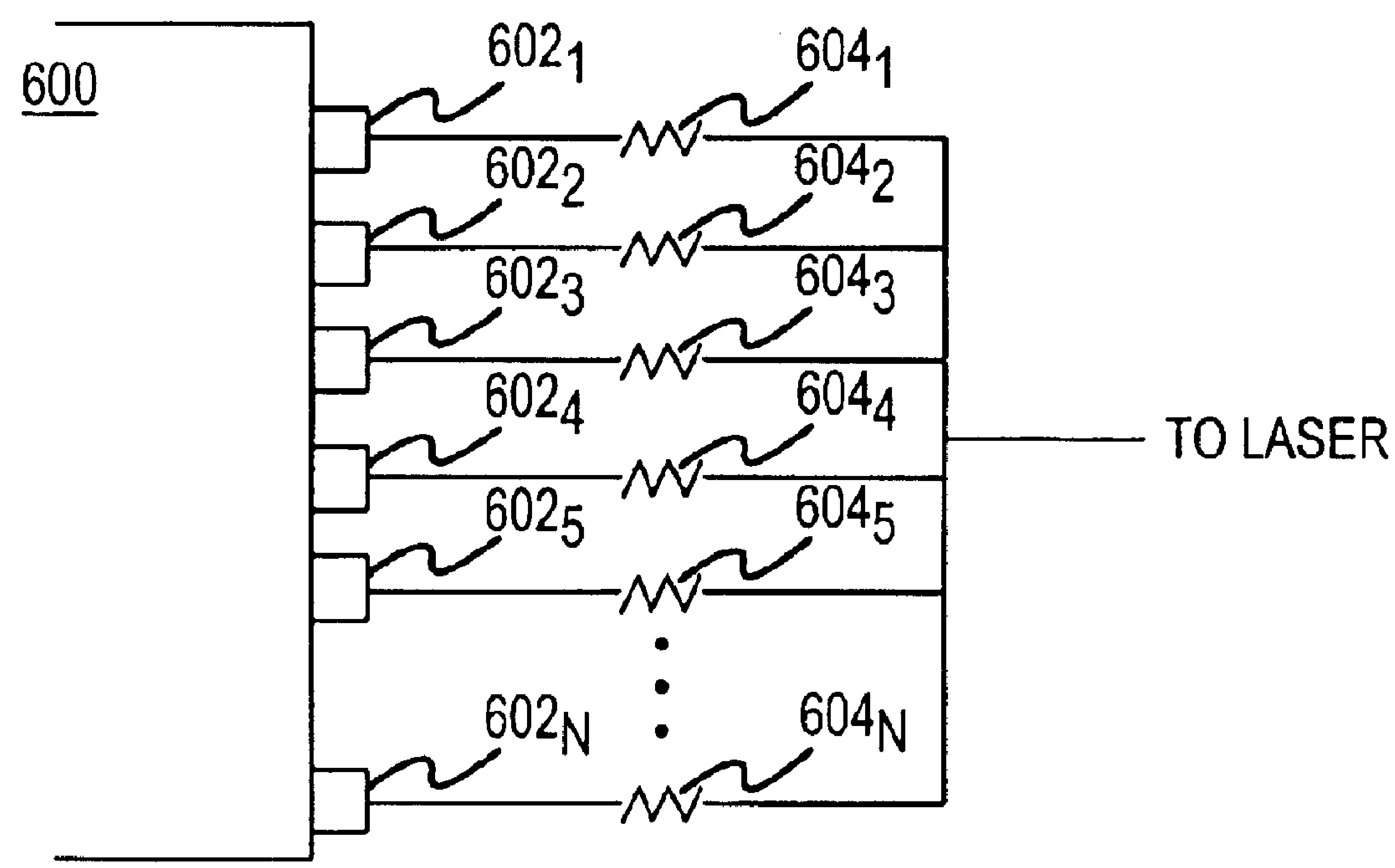
(57) **ABSTRACT**

Apparatus for digitally driving a laser in a passive optical network includes a programmable current source having an output terminal connected to supply current to the laser. The programmable current source includes a plurality of output pins, each of the outputs pins has a voltage thereon, all of the output pins are connected to the output terminal, and one or more of the output pins is connected to the output terminal through a resistor. A controller supplies a digital control signal to the programmable current source to specify which of the output pins are to be turned on, to thereby determine the magnitude of a current supplied to the laser from the output terminal.

24 Claims, 11 Drawing Sheets



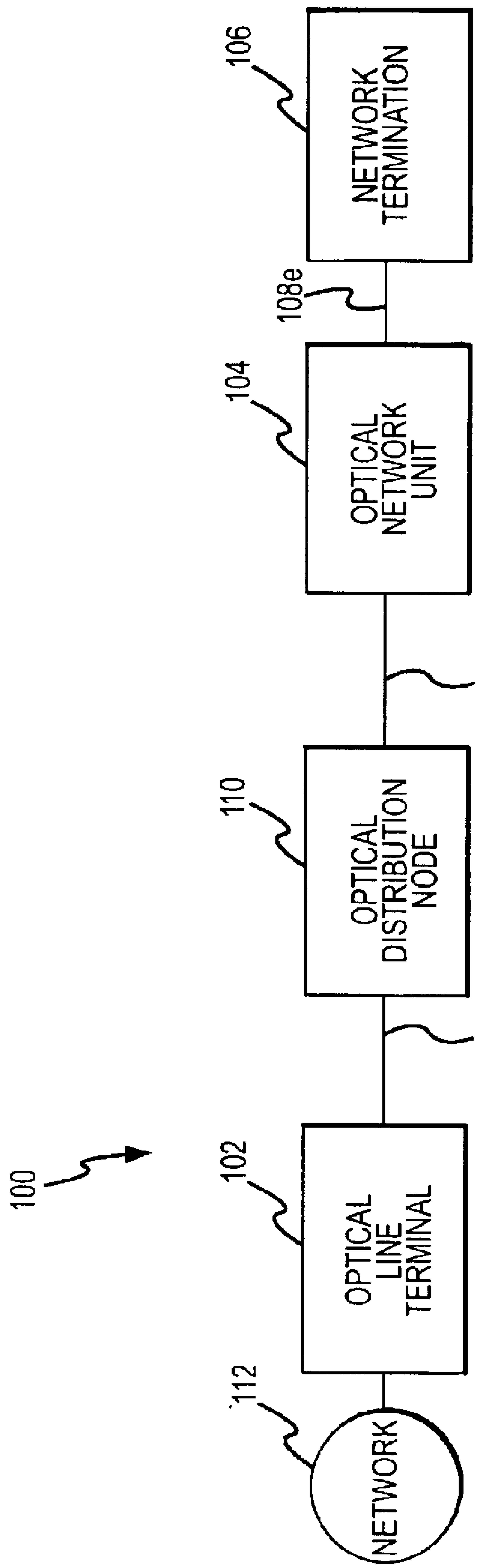
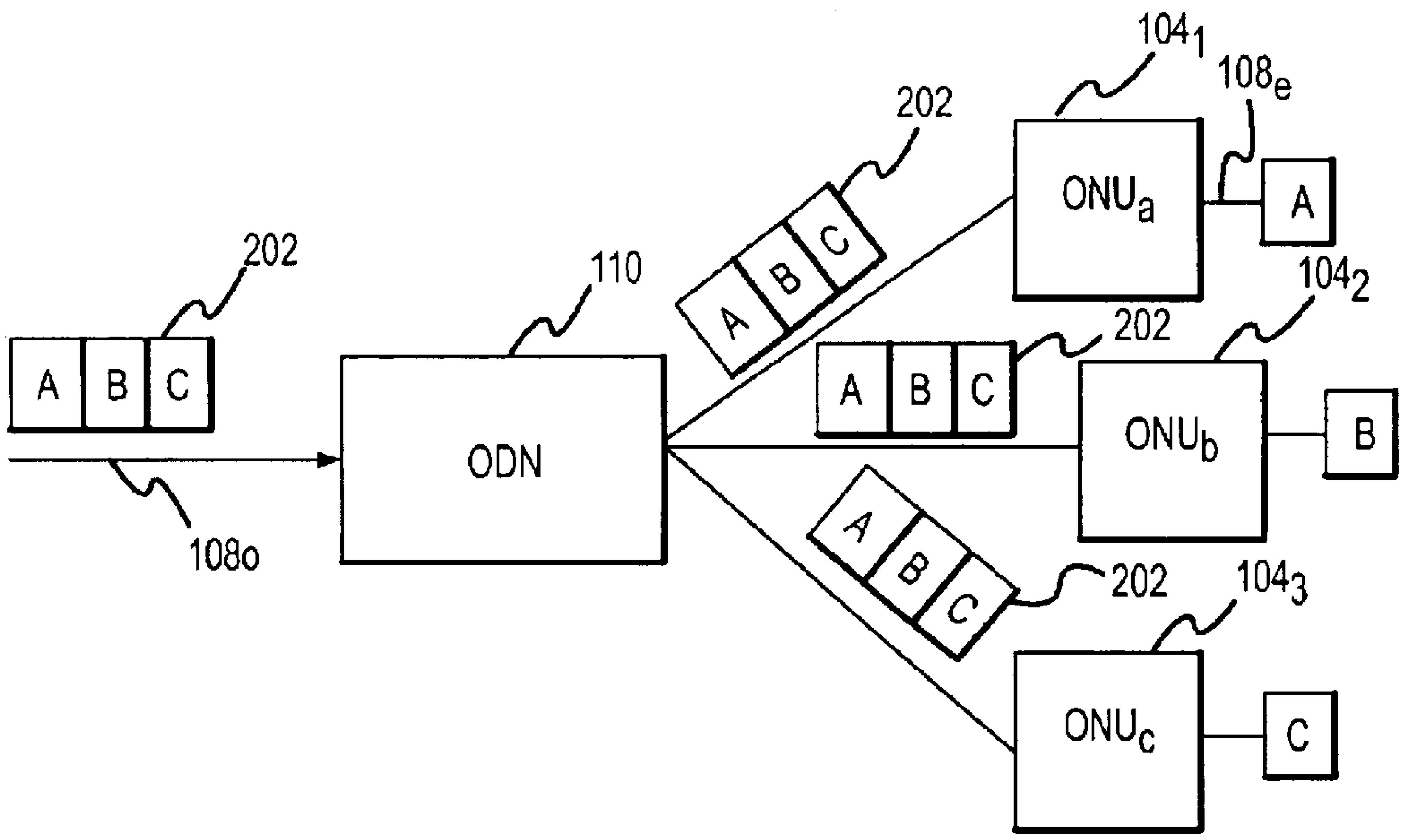

106
NETWORK TERMINATION
108e
104
OPTICAL NETWORK UNIT
108e
110
OPTICAL DISTRIBUTION NODE
108e
100
102
OPTICAL LINE TERMINAL
112
NETWORK

FIG.1



202
A
B
C
108o
110
ODN
202
A
B
C
104₁
108e
ONUa
A
104₂
202
A
B
C
ONUb
B
A
B
C
202
104₃
ONUc
C

FIG.2

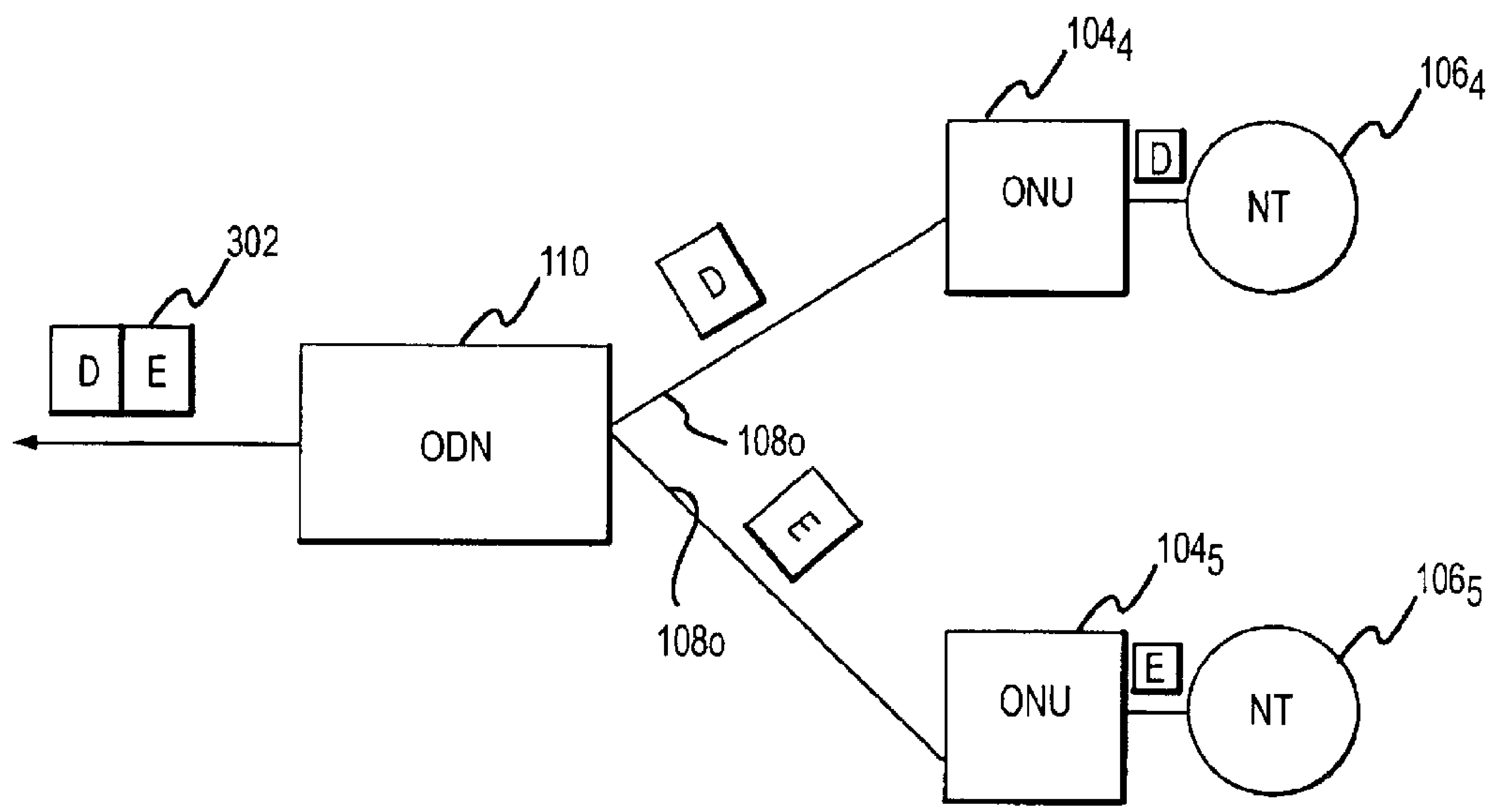


FIG.3

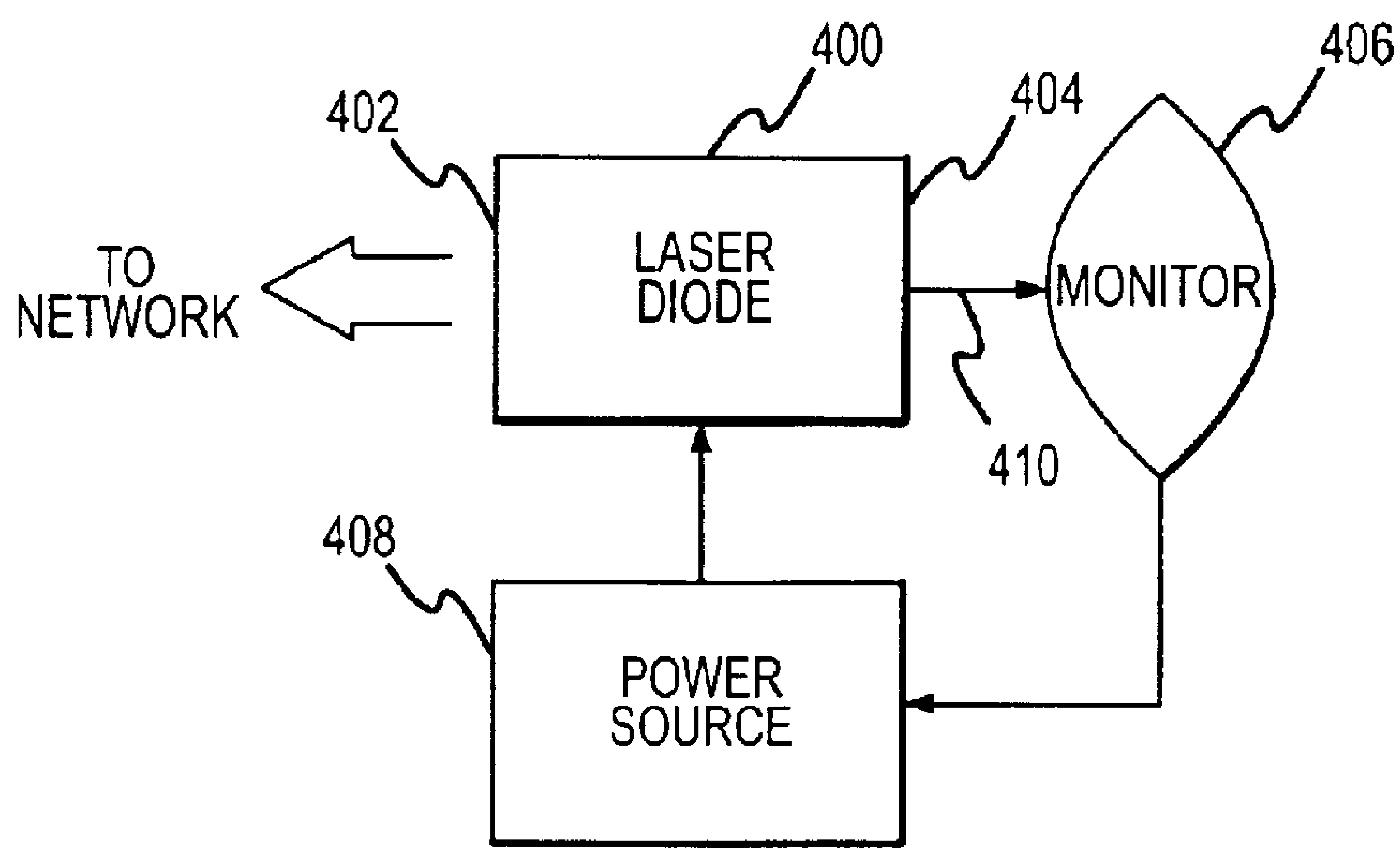

400
402
404
406
TO
NETWORK
LASER
DIODE
MONITOR
410
408
POWER
SOURCE

FIG.4

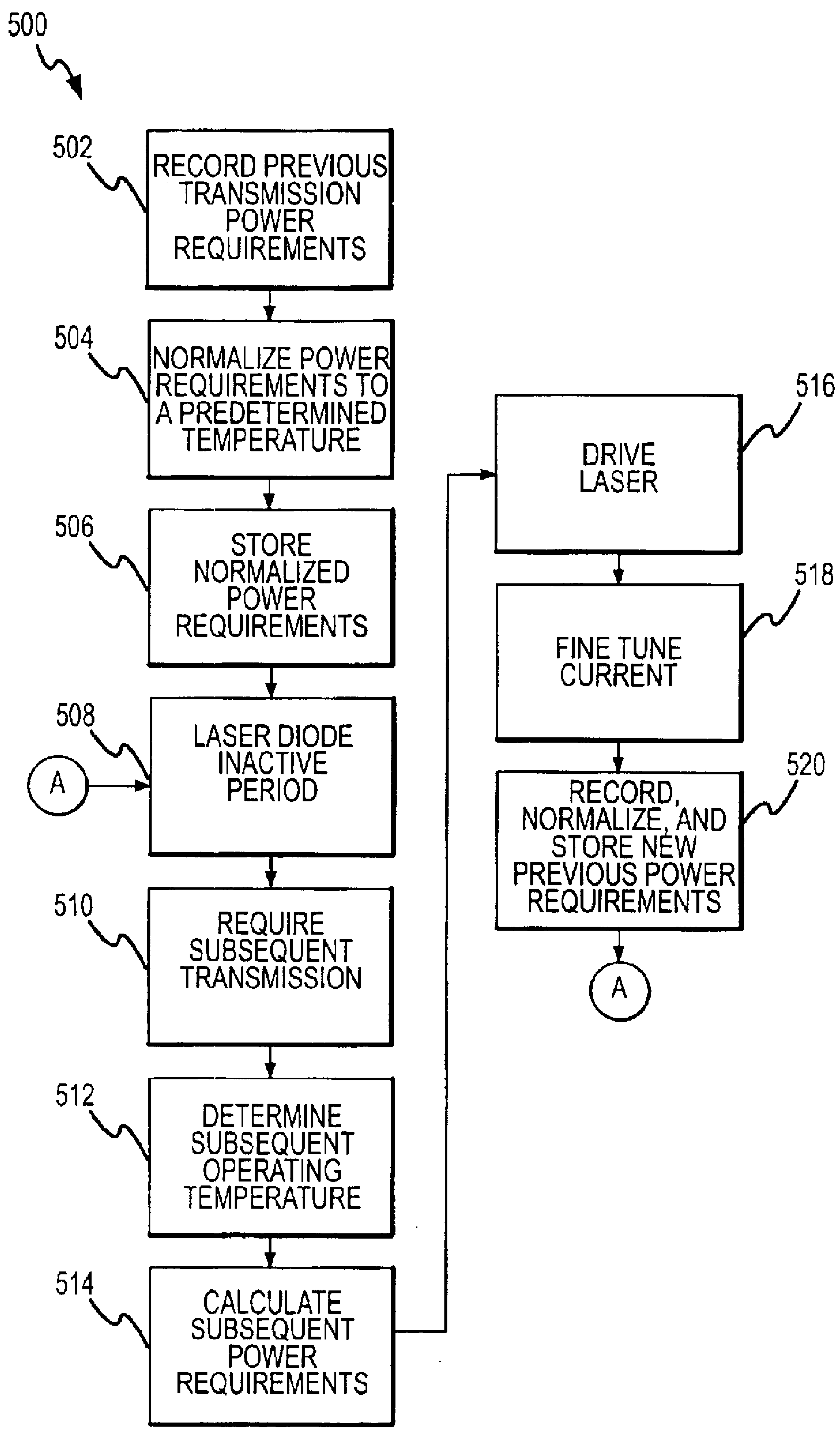

500
502
RECORD PREVIOUS TRANSMISSION POWER REQUIREMENTS
504
NORMALIZE POWER REQUIREMENTS TO A PREDETERMINED TEMPERATURE
506
STORE NORMALIZED POWER REQUIREMENTS
508
A
LASER DIODE INACTIVE PERIOD
510
REQUIRE SUBSEQUENT TRANSMISSION
512
DETERMINE SUBSEQUENT OPERATING TEMPERATURE
514
CALCULATE SUBSEQUENT POWER REQUIREMENTS
516
DRIVE LASER
518
FINE TUNE CURRENT
520
RECORD, NORMALIZE, AND STORE NEW PREVIOUS POWER REQUIREMENTS
A

FIG.5

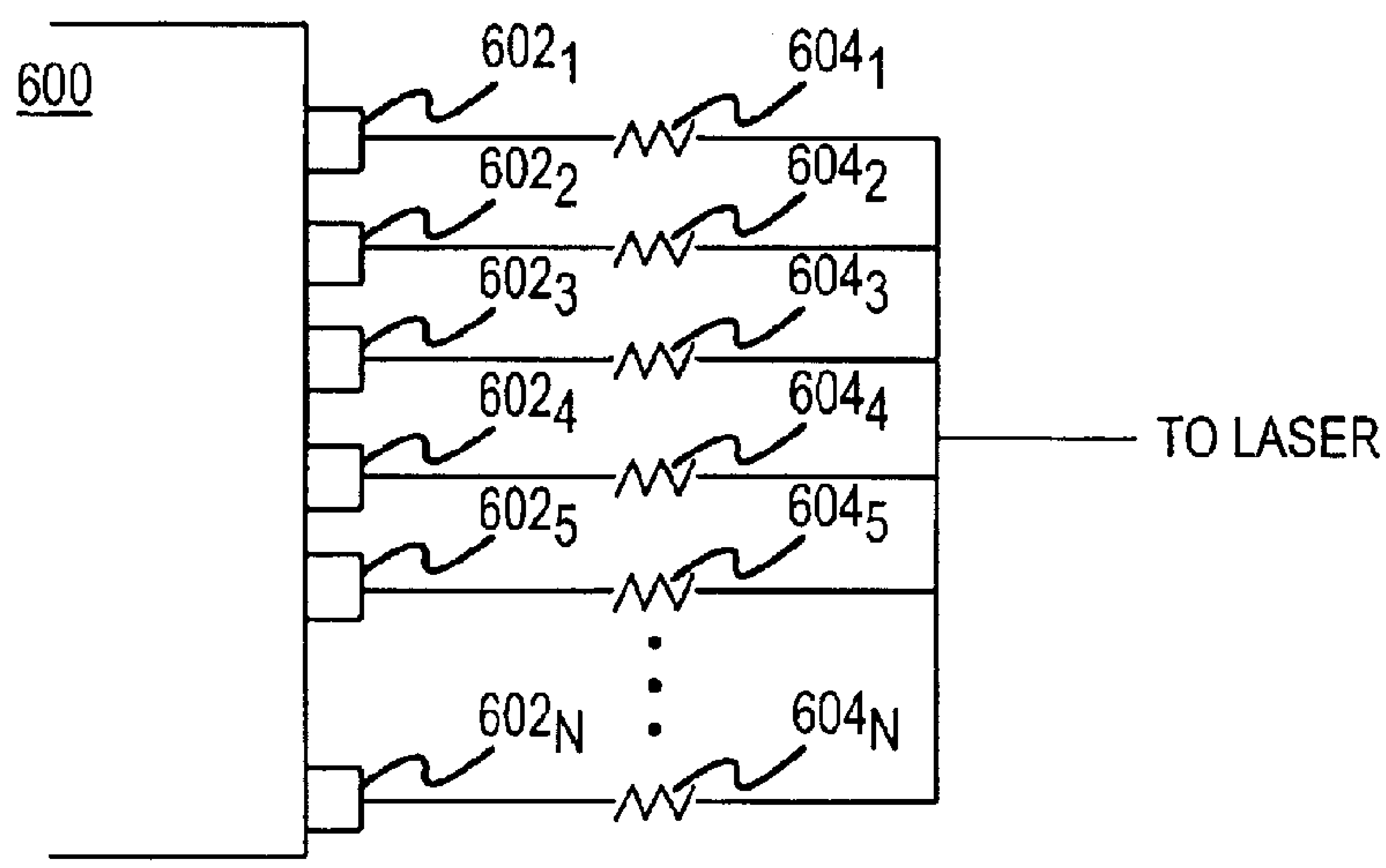

600
602₁
604₁
602₂
604₂
602₃
604₃
602₄
604₄
602₅
604₅
602N
604N
TO LASER

FIG.6

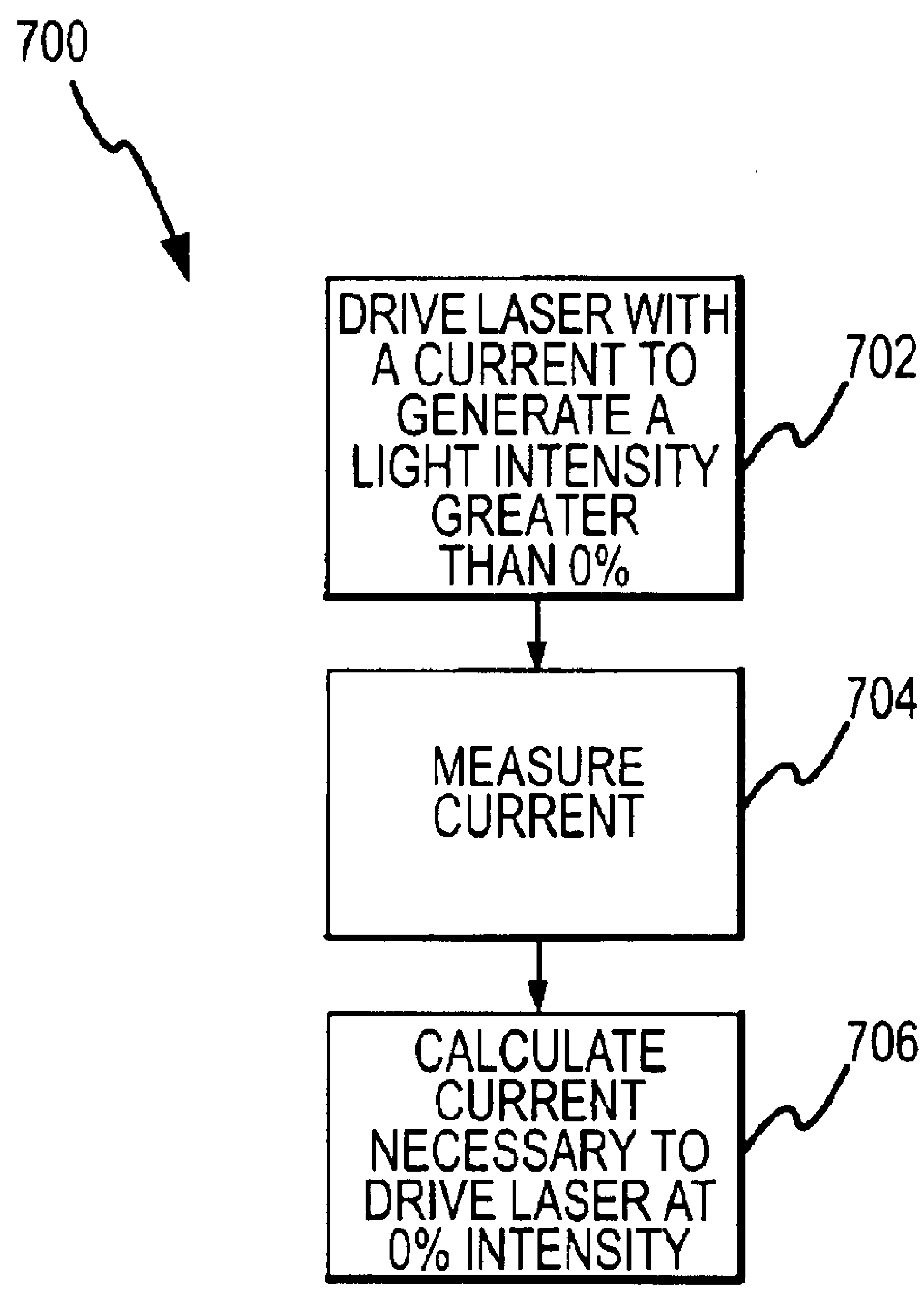

700
DRIVE LASER WITH A CURRENT TO GENERATE A LIGHT INTENSITY GREATER THAN 0%
702
MEASURE CURRENT
704
CALCULATE CURRENT NECESSARY TO DRIVE LASER AT 0% INTENSITY
706

FIG.7

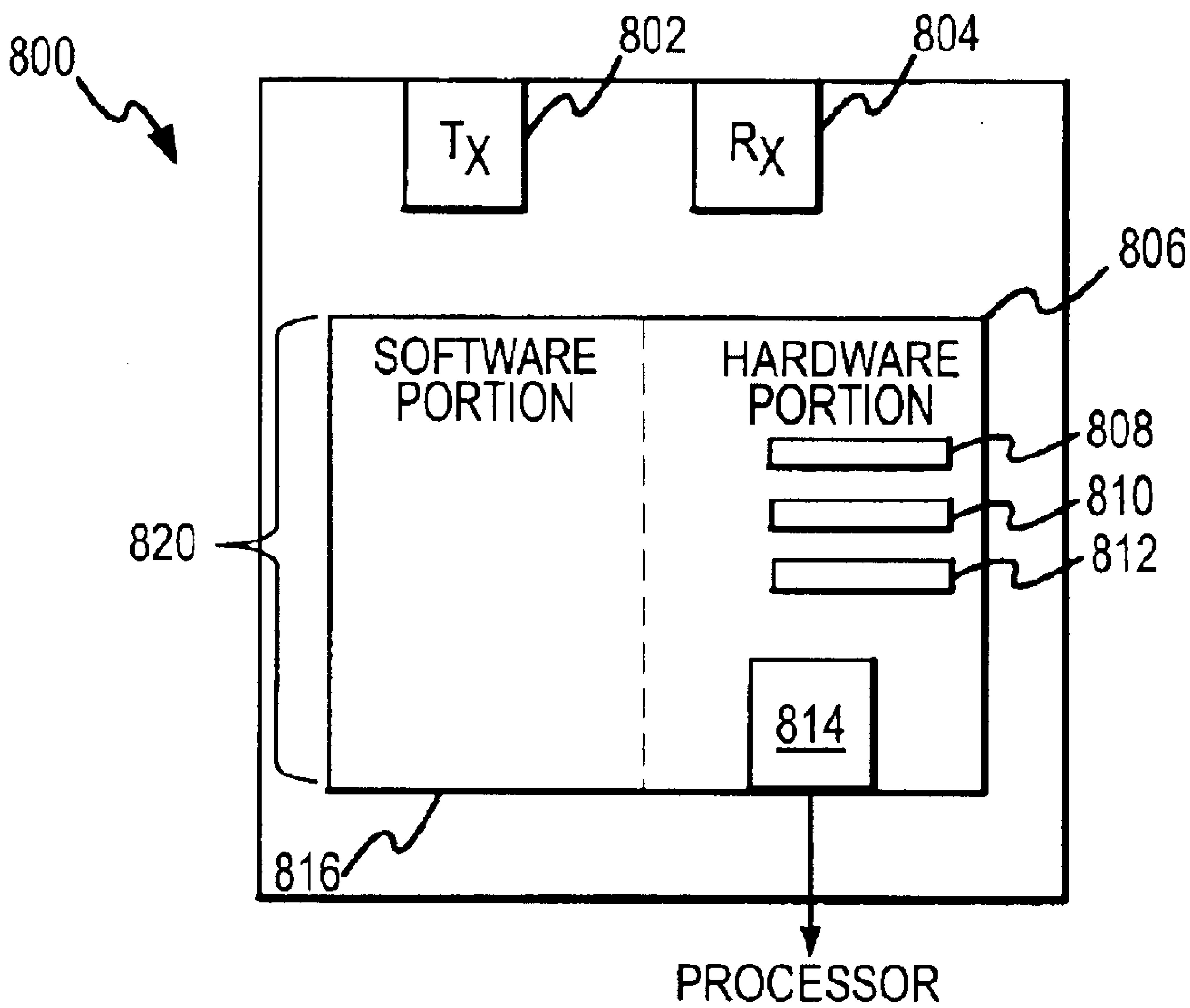

800
802
804
TX
RX
806
SOFTWARE PORTION
HARDWARE PORTION
808
810
812
820
814
816
PROCESSOR

FIG.8

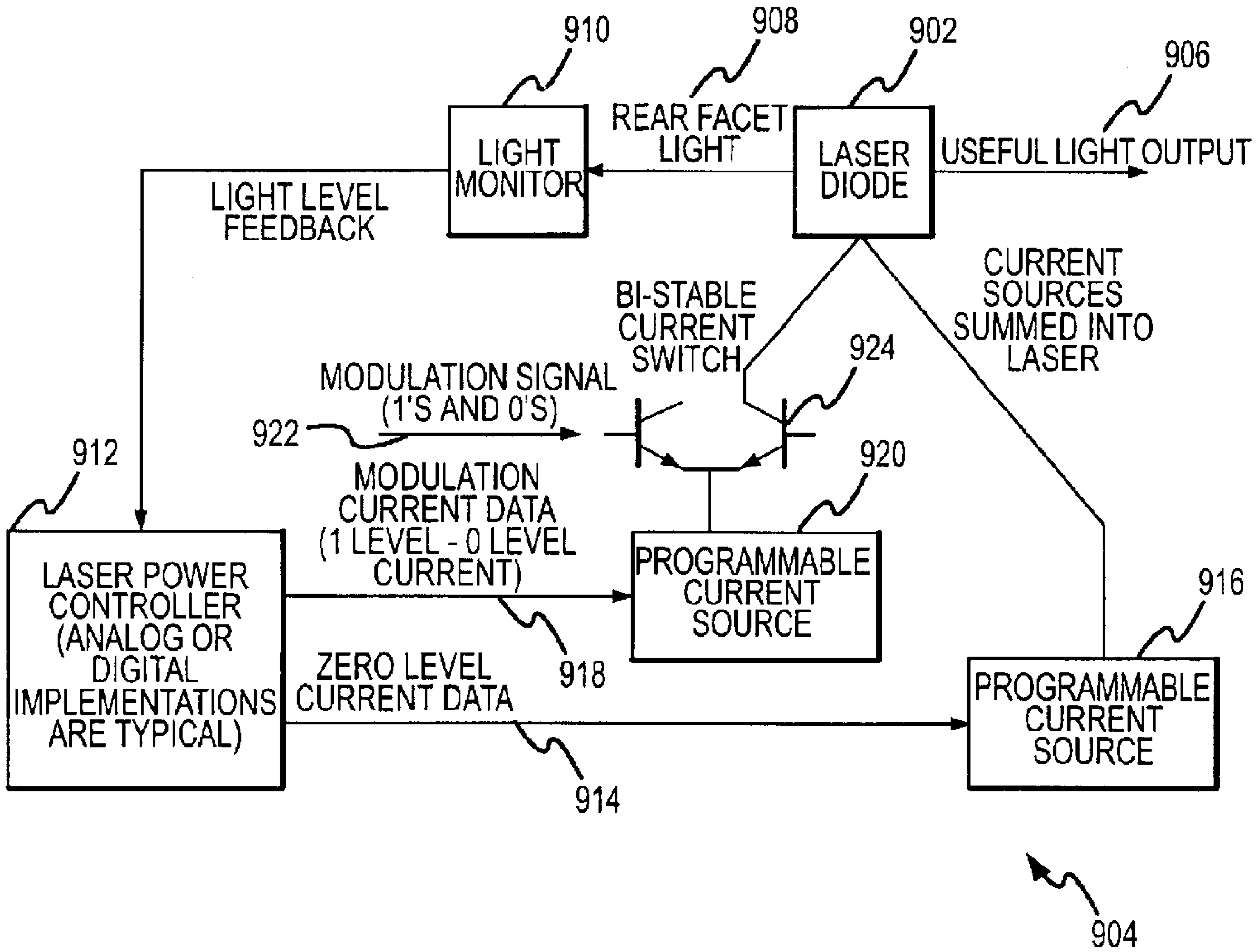
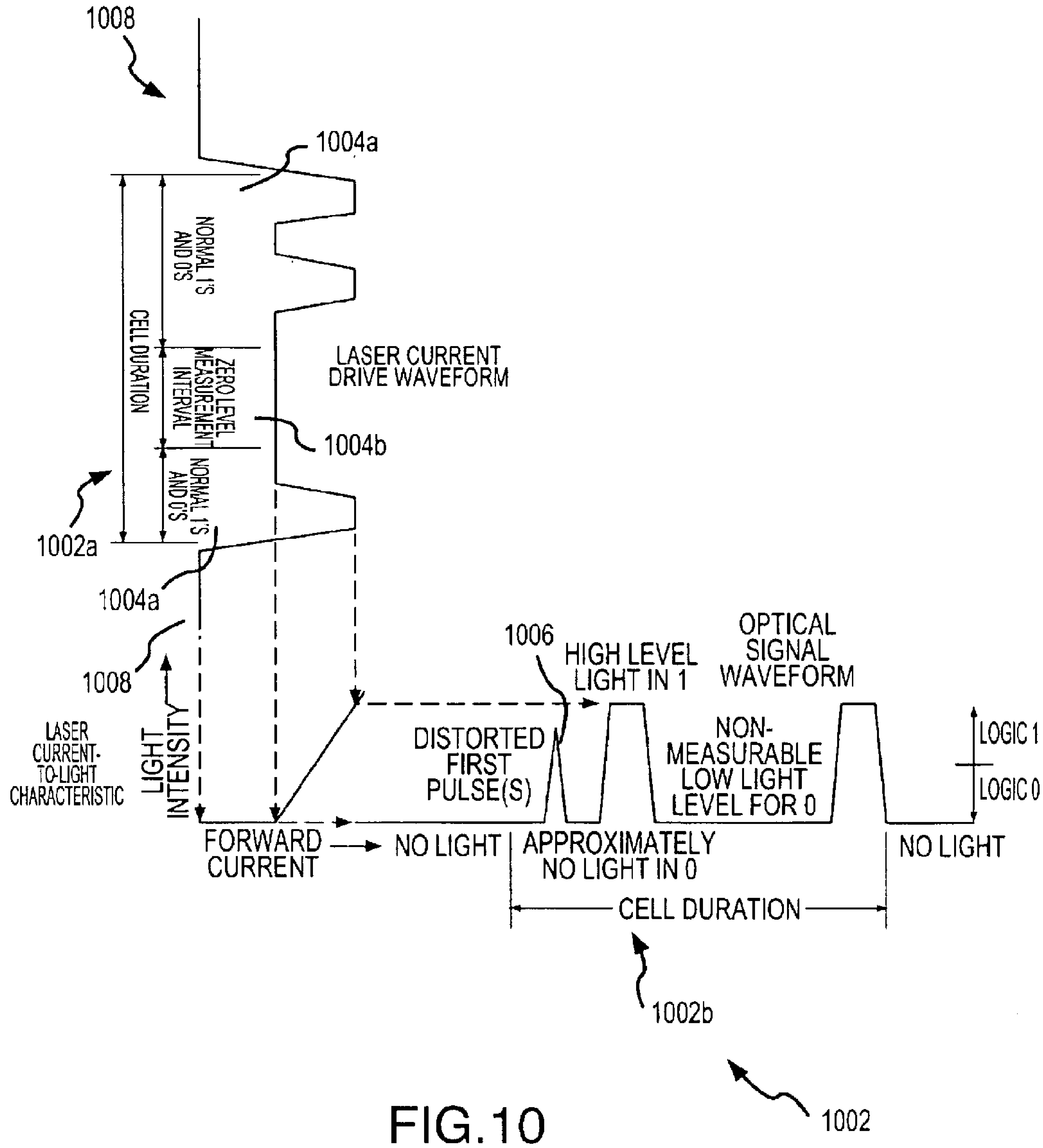

910
908
902
906
LIGHT MONITOR
REAR FACET LIGHT
LASER DIODE
USEFUL LIGHT OUTPUT
LIGHT LEVEL FEEDBACK
CURRENT SOURCES SUMMED INTO LASER
BI-STABLE CURRENT SWITCH
924
MODULATION SIGNAL (1'S AND 0'S)
922
920
912
MODULATION CURRENT DATA (1 LEVEL - 0 LEVEL CURRENT)
LASER POWER CONTROLLER (ANALOG OR DIGITAL IMPLEMENTATIONS ARE TYPICAL)
PROGRAMMABLE CURRENT SOURCE
916
918
ZERO LEVEL CURRENT DATA
PROGRAMMABLE CURRENT SOURCE
914
904

FIG.9



1008
1004a
NORMAL 1'S AND 0'S
CELL DURATION
ZERO LEVEL MEASUREMENT INTERVAL
LASER CURRENT DRIVE WAVEFORM
1004b
NORMAL 1'S AND 0'S
1002a
1004a
1008
LASER CURRENT-TO-LIGHT CHARACTERISTIC
LIGHT INTENSITY
FORWARD CURRENT
1006
HIGH LEVEL LIGHT IN 1
OPTICAL SIGNAL WAVEFORM
DISTORTED FIRST PULSE(S)
NON-MEASURABLE LOW LIGHT LEVEL FOR 0
LOGIC 1
LOGIC 0
NO LIGHT
APPROXIMATELY NO LIGHT IN 0
NO LIGHT
CELL DURATION
1002b
1002

FIG.10

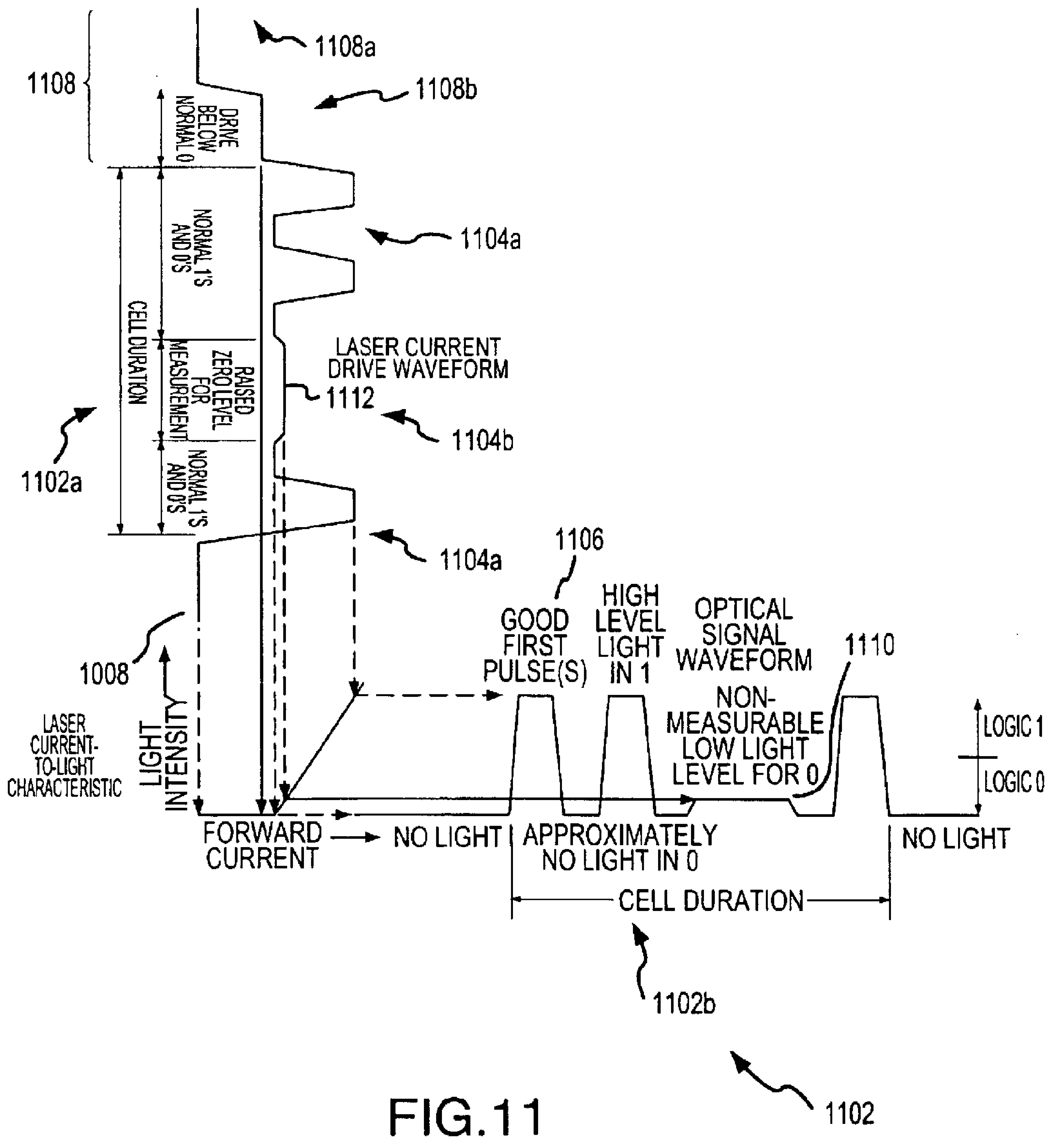

1108
1108a
1108b
DRIVE BELOW NORMAL 0
NORMAL 1'S AND 0'S
1104a
CELL DURATION
RAISED ZERO LEVEL FOR MEASUREMENT
LASER CURRENT DRIVE WAVEFORM
1112
1104b
1102a
NORMAL 1'S AND 0'S
1104a
1106
1008
GOOD FIRST PULSE(S)
HIGH LEVEL LIGHT IN 1
OPTICAL SIGNAL WAVEFORM
1110
NON-MEASURABLE LOW LIGHT LEVEL FOR 0
LOGIC 1
LOGIC 0
LASER CURRENT-TO-LIGHT CHARACTERISTIC
LIGHT INTENSITY
FORWARD CURRENT
NO LIGHT
APPROXIMATELY NO LIGHT IN 0
NO LIGHT
CELL DURATION
1102b
1102

FIG.11

METHODS AND APPARATUSES FOR DIRECT DIGITAL DRIVE OF A LASER IN A PASSIVE OPTICAL NETWORK

RELATED APPLICATIONS

This application claims the benefit of U.S. patent application Ser. No. 60/382,506, filed May 21, 2002, titled Methods and Apparatuses for Optical Network Termination and Media Access Control in a Passive Optical Network.

FIELD OF THE INVENTION

The present invention relates to an optical network and, more particularly, a hardware implementation of the APON protocols, a direct digital drive of a laser diode, and measurement and control system for the direct digital drive of the laser diode.

BACKGROUND OF THE INVENTION

A passive optical network (PON) is an optical network that distributes signals to multiple terminal devices using passive splitters without active electronics, such as, for example, repeaters. Conventionally, signal delivery over passive networks uses a variety of transfer protocols, such as, for example, a synchronous optical network (SONET) or an asynchronous transfer mode (ATM) protocols. From time to time, the International Telecommunication Union (ITU) issues recommendations and standards for PONs under standard G.983.1, which standard is incorporated herein by reference. Generally, the present invention is described with relation to APON, asynchronous transfer mode passive optical networks and the associated protocols, but one of ordinary skill in the art would understand that the use of APON is illustrative of the present invention and the present invention could be used for other types of passive optical networks, for example, EPON.

FIG. **1** illustrates a conventional APON **100**. APON **100** could be either a fiber to the building (FTTB) or a fiber to the home (FTTH) network configuration. Generally, the PON system comprises an optical line terminal (OLT) **102**, at least one optical network unit (ONU) **104**, and at least one network termination (NT) **106** where an end user can access the system using, for example, a conventional computer, processor, or the like (not specifically shown). Connections **108***o* from the OLT **102** to the ONU **104** are fiber or optical connections and connections **108***e* from the ONU **104** to the NTs **106** are electrical connections. Depending on the number of ONUs **104** and NTs **106**, one or more optical distribution nodes (ODN, a.k.a optical splitters and combiners) **110** may be situated between OLT **102** and ONU **104**. Generally, ONUs **104** and NTs **106** reside at the end user or subscriber location (not specifically shown).

FIG. **9** illustrates a laser diode **902** using a conventional power source control system **904**. As shown, laser diode **902** emits useful light **906** and rear facet light **908**. Useful light **906** refers to light transmitted to connection **108***o*. A light monitor **910**, which could be a photodiode, a light meter, or the like, senses the intensity of rear facet light **908**. The intensity of rear facet light **908** corresponds to the intensity of useful light **906**. Substantially simultaneously with sensing the intensity of rear facet light, light monitor **910** supplies a light level feedback signal to a laser power controller **912**. Laser power controller **912** supplies a zero level current data signal **914** to a first programmable current source **916**. First programmable current source **916** supplies the current necessary to drive laser diode **902** at the light intensity that corresponds to a logic level zero. Laser power controller **912** also supplies a modulation current data signal **918** to a second programmable current source **920**. The modulation current data signal **918** determines the light intensity of the useful light output **906**. A modulation signal **922** is supplied to the gate of a bi-stable switch **924** to turn the switch on and off based on whether the useful light intensity **906** should be at the logic 1 or the logic 0 intensity. The bi-stable switch passes current from the programmable current source **920** to be summed with the current from programmable source **916**. The sum of the two currents drives laser diode **902**. The feedback signal to laser power controller **912** allows fine-tuning of the drive currents so the average intensity of the light signal remains within the protocol requirements for logic levels 1 and 0. These current vary widely from laser diode to laser diode ranging from as low as 2 or 3 milliamps to as high as 50 to 60 milliamps.

FIG. **10** is a diagrammatic representation of useful light intensity to drive current. In particular, FIG. **10** shows transmission of an information cell **1002**. As is known in the art, cell **1002** is an ATM protocol for transmitting information. FIG. **10** (and FIG. **11**) does not actually represent transmission of a complete cell of information, but rather a short burst of information for convenience. Cell **1002***a* represents drive current for exemplary cell **1002** and cell **1002***b* represents light intensity for exemplary cell **1002**. As shown, cell **1002***a* can be considered in discrete parts **1004***a* and **1004***b*. Part **1004***a* is the drive current necessary for the transmission of light bearing information having an intensity of logic 1s and 0s. Part **1004***b* is the drive current for the transmission of light having an intensity of logic 0 to allow for a zero level measurement only; in other words, no information is being transmitted during the zero level measurement. The duration and timing of part **1004***b* is generally controlled by the associated transmission protocols. Similarly, light intensity shown by cell **1002***b* over the course of cell **1002** transitions between the high and low drive currents for the laser diode. As the diagram shows, because of difficulties in controlling the drive current for the laser diode, first logic pulse **1006** is typically wasted adjusting the drive current for the existing operating conditions and temperatures. Part of the difficulty of controlling current occurs because the lasing cavity needs to charge the photons sufficiently to begin emitting light. Also, when the photons in the lasing cavity are sufficiently charged to the threshold or knee level, the laser emits a burst of light and oscillates until the photons are properly charged and the laser is correctly operating above the threshold level.

As can be seen from FIG. **10**, during non-transmission period **1008**, laser diode **902** is driven at a 0 current. Laser diode **902** is driven with a 0 current to inhibit the accidental transmission of light from laser diode **902** when laser diode **902** does not have a transmission grant. The drive current for a logic level 0 light intensity is some current greater than 0 current. Thus, one reason the first logic pulse **1006** is wasted is that time during the transmission of cell **1002** is required to charge the photons in the laser. While maintaining the laser drive current at the zero logic drive current (which is greater than 0 amps) would maintain the laser charged, it might allow for inadvertent light emission from the laser, which would cause interference with other transmitting lasers.

Transmission of a cell of information will be further explained with reference to FIGS. **1–3**. Using ATM protocols, OLT **102** receives incoming cells **202** of information from a transport network or service node **112** destined for NTs **106**. For simplicity, this example has three cells of information ABC destined for three separate NTs **106**. The transport network could be any style network, such as the Internet, a Plain Old Telephone Service (POTS), digital video and/or audio streams. OLT **102** routes the incoming cell **202** over optical connection **108***o* through ODN **110** to three ONUs $\mathbf{104}_{1\text{-}3}$. Using conventional protocols associated with APON, ONU $\mathbf{104}_{1\text{-}3}$ selects the data for its associated NT **106** and converts the optical signal to an electrical signal for distribution to the NT **106** over connection **108***e*. For example, ONU_a selects data cell A from incoming cell **202** and converts that data into an electrical signal for NT **106**.

FIG. **3** shows the transmission of outgoing information from two NTs $\mathbf{106}_4$ and $\mathbf{106}_5$, for example. NT $\mathbf{106}_4$ transmits an outgoing data cell D and NT $\mathbf{106}_5$ transmits an outgoing data cell E over connection **108***e* to ONUs $\mathbf{104}_4$ and $\mathbf{104}_5$. The ONUs $\mathbf{104}_4$ and $\mathbf{104}_5$ converts the electrical signal to an optical signal for transmission to ODN **110** over connection **108***o*. ODN **110** combines the data cells D and E into a single cell stream **302**. To prevent data collisions, APON protocols require ONUs **104** to transmit data cells at specific times and in short bursts. Thus, the laser diode (not specifically shown) associated with ONU **104** typically transmits a cell lasting a fraction of a microsecond or a burst of cells lasting a few microseconds, but may only transmit infrequently. Also, the laser diode typically transmits regularly, but may be powered down for an indeterminate length of time, which may change the laser diode's operating characteristics including the laser diode's operating temperature. Because the subscriber side laser diode may only transmit data infrequently and when it does transmit data the transmission is only a short burst of information, it is difficult to control the laser power input and light intensity.

As can be seen from the above, it would be beneficial to provide improved methods and apparatuses for measuring and controlling the power and intensity of the laser diode associated with the passive optical networks.

SUMMARY OF THE INVENTION

The foregoing and other features, utilities and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention as illustrated in the accompanying drawings.

To attain the advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, apparatuses to drive a laser in a passive optical network are provided. Apparatuses generally include a laser with a power supply controller coupled to a programmable logic device (commonly a field programmable gate array). The power supply controller transmits a drive signal to the programmable logic to turn on output pins. The drive current supplied to the laser depends on the combination of output pins turned on.

The present invention further provides methods for driving a laser in a passive optical network. The methods include generating a laser drive signal from a power supply controller and receiving the laser drive signal at a programmable logic device. At least one output pin of the programmable logic device is turned on based on the signal to supply current to the laser.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate some preferred embodiments of the invention and, together with the description, explain the goals, advantages and principles of the invention. In the drawings,

FIG. **1** is functional block diagram of a conventional passive optical network;

FIG. **2** is a functional block diagram of a conventional passive optical network transmitting information from the transport network to the network terminations;

FIG. **3** is a functional block diagram of a conventional passive optical network transmitting information from the network terminations to the transport network;

FIG. **4** is a functional block diagram of a laser diode power control feedback loop in accordance with one aspect of the present invention;

FIG. **5** is a flowchart **500** illustrative of powering a laser in accordance with one aspect of the present invention;

FIG. **6** is a functional block diagram of a direct digital drive for a laser in accordance with one aspect of the present invention;

FIG. **7** is a flowchart **700** illustrative of controlling a laser drive in accordance with one aspect of the present invention;

FIG. **8** is a functional block diagram of an ONU in accordance with one aspect of the present invention;

FIG. **9** is a functional block diagram of a prior art laser diode power supply;

FIG. **10** is a graphical representation of prior art laser current to light characteristics; and

FIG. **11** is a graphical representation of laser current to light characteristics consistent illustrative of aspects of the present invention.

DETAILED DESCRIPTION

With reference to FIGS. **1–11**, the present invention will be described. It is intended that all matter contained in the description below or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

FIG. **4** shows a laser diode **400** illustrative of the present invention. While laser diodes are the typical lasing device for passive optical networks, other lasing devices could be used. Laser diode **400** includes a first lasing side **402** and a second side **404**. First lasing side **402** emits light to the passive optical network (not shown in FIG. **4**) while second lasing side **404** emits light to an intensity monitor **406**, such as a photodiode or the like. Intensity monitor **406** sends a feedback signal to control a power source **408** that drives the laser diode **400**. Thus, for example, when transmitting a logic 1 from laser diode **400**, the laser diode **400**'s light intensity must be a certain intensity. Intensity monitor **406** would measure the intensity of a light beam **410**. If the intensity of light beam **410** is below the logic 1 threshold, then the power source increases the power input to laser diode **400**. Increasing the power input to laser diode **400** increases the intensity of light beam **410**. Similarly, if the intensity is too high, the power is decreased. A logic 0 transmission would be controlled in a similar fashion.

The power source typically uses analog components, such as a bi-stable analog switch, to provide power to the laser. The analog components control power to the laser diode, which in turn controls the light intensity out of the laser. The analog power source, as referenced above, is a conventional device and will not be further explained.

The power necessary to drive the laser so that the light intensity is the correct level, however, is a function of wide device-to-device characteristics, the laser's aging characteristics, and the laser's operating temperature. Further, if the laser is inadvertently overpowered, the laser can be damaged. Thus, most current systems waste the initial portion of the lasing period in order to ramp the light intensity up to the desired level. Further, the analog power source design is a complex solution that requires numerous, relatively expensive parts. Finally, the analog power source provides rapid transition between the logic 1 and the logic 0 states, but does not conveniently provide a means to rapidly vary each of the currents to the laser at the logic 1 or 0 currents, respectively.

FIG. **5** shows a flowchart **500** indicative of a method of initially powering the laser diode **400** so that on its next transmission, the initial current supplied by power source **408** is approximately the correct power for the desired light intensity. First, during a previous transmission of signal from laser diode **400**, the previous transmission of power requirements for a logic 0 signal and a logic 1 signal are recorded, step **502**. While the previous transmission power requirements can be stored as analog data, if the analog data is converted to digital data, the information can be maintained for a longer duration, which may become important depending on the time delay between the previous and subsequent data transmissions. The previous transmission power requirements are then normalized to a predetermined temperature, such as 25° C., step **504**. The normalized power requirement to generate a light intensity for logic 0 and the power requirement to generate a light intensity for logic 1 are stored, step **506**. Notice, if the previous transmission power requirements are not normalized, the pervious transmission actual temperature could be stored, as will be explained further below. Next, the laser diode is inactive for an indefinite period of time, which could be several microseconds, seconds, minutes, hours, days, weeks, months, years, etc., step **508**. The inactive period is generally contemplated to be a time when the laser diode is turned off, but the laser diode can be inactive for any number or reasons. Eventually, the laser diode is required to transmit a logic 0, a logic 1, or some combination of logic 0s and 1s in a subsequent transmission, step **510**. At the time the subsequent transmission is required, a temperature sensor records subsequent transmission temperature, step **512**. Using the subsequent transmission temperature, subsequent transmission power requirements for transmission of a logic 0 and a logic 1 are calculated from the stored normalized power requirements, step **514**. As mentioned above, if the previous transmission power requirements are not normalized, the previous transmission temperature, the subsequent transmission temperature, and the previous transmission power requirements are used to calculate the subsequent transmission power requirements. The laser diode **400** is driven by the calculated subsequent transmission power requirements, step **516**. Typically, the laser diode **400** is not precisely driven, so conventional feedback loops are used to fine tune the power needed to drive the laser diode to the correct intensities, step **518**. Because the calculated subsequent transmission power requirements for the laser diode are sufficiently close to the actual power requirements, less time for each transmission burst is wasted adjusting the laser power to provide the correct intensity. Further, by applying approximately the correct drive power, the laser diode is less likely to be damaged by overdriving. Finally, during the subsequent transmission, new previous power requirements are recorded normalized, and stored for logic 0 and logic 1 transmissions, step **520**, and the laser enters an inactive period, step **508**. Current APON protocols identify at what points during transmission of a cell the power levels for logic 0 and/or logic 1 should be measured. Notice, new previous power requirements do not need to be obtained each subsequent transmission. Rather, it is possible to store power requirements on some time interval or some predetermined number of transmission, although replacing the stored power requirements each transmission would likely provide better initial power estimates for each subsequent transmission.

Direct Digital Drive

As mentioned above, conventional power sources to drive laser diode **400** utilize analog components. The analog solution components are relatively expensive and relatively numerous. In other words, as shown in FIG. **9**, the digital signal from the processor **912** is supplied to analog power sources **916**, **920**. A control signal to the bi-stable switch **924** causes analog current to be supplied to the laser. It would be beneficial to supply the control signal from processor **912** to digital to analog ("DAC") converter (not specifically shown in FIG. **9**). The DAC would use the digital control signal to supply an analog current to the laser. While a conventional DAC could be used, one of skill in the art would recognize that other converters are possible, such as ASIC silicon, customized microchips, or specialty DAC components. One of skill in the art would further recognize that programmable logic, such as field programmable gate arrays, are also possible. The below relates to the use of programmable logic, but one of skill in the art would recognize on reading the below, that multiple converters are possible.

Using, resistors and logic for a direct digital drive requires several relatively cheap resistors and the use of part of a programmable logic part, such as an FPGA, that is conventionally available in a PON transceiver and typically has some un-used logic. FIG. **6** is a functional diagram of a digital power source **600** for the laser. Current embodiments of the digital power source **600** comprise a field programmable gate array (FPGA), but as one of ordinary skill in the art would recognize on reading this disclosure, other digital devices could be used. FPGA **600** includes a number of pins $\mathbf{602}_{1\text{-}n}$ and a number of resistors $\mathbf{604}_{1\text{-}m}$. Generally, each pin has a corresponding resistor. Each pin **602** of FPGA **600** is driven by a particular voltage, such as, for example, 3 volts. For pin $\mathbf{602}_1$ to supply, for example, 1 milliamp of incremental current drive to the laser (not shown in FIG. **6**), then resistor $\mathbf{604}_1$ would be 3K ohms. For pin $\mathbf{602}_2$ to supply, for example, 2 milliamps of incremental current drive to the laser, then resistor $\mathbf{604}_2$ would be 1.5K ohms. For pin $\mathbf{602}_3$ to supply, for example, 4 milliamps of incremental current drive to the laser, then resistor $\mathbf{604}_3$ would be 750 ohms. For pin **6024** to supply, for example, 8 milliamps of incremental current drive to the laser, then resistor $\mathbf{604}_4$ would be 375 ohms, etc. Thus, if the laser required 13 milliamps to supply a logic 1 light intensity, pins $\mathbf{602}_1$, $\mathbf{602}_3$, and $\mathbf{602}_4$ would be used to drive the laser. For 10 milliamps, pins $\mathbf{602}_2$ and $\mathbf{602}_4$ would be used to drive the laser. As one of ordinary skill in the art would recognize on reading this disclosure, any number of combinations of output voltage and resistors could be used to provide the required combination of potential voltages. Further, while the above is shown using 1 milliamp steps smaller or larger increments could be designed for as a matter of design choice. Of course, instead of using a binary progression as shown, each pin could be capable of the same currently. For example, each pin **602** could each drive 1 milliamp. Still further, a combination of a binary progression and equally weight currents could be used. Still further, binary groupings would be possible, such as groups of 4 pins supply 1 to 15 milliamps. In other words, each group of pins has a 1 milliamp pin, a 2 milliamp pin, a 4 milliamp pin and an 8 milliamp pin. In this case, two groups would be used to supply 16 milliamps, which could all pins of 1 group and 1 milliamp from another, or 2 8 milliamp pins, etc. To provide, for example, up to 50 milliamps, four groups of pins would be provided. Of course, other combinations could be used as a matter of design choice and availability. For even greater control, adding pulse width modulation and filtering capacitance on one or more pins to maintain a relatively consistent DC output for one or more pins provides further precision control of the current drive. The additional precision is achieved, in part, because the pin's DC output could be controlled between essentially zero milliamps and the maximum milliamps.

Referring back to FIG. **9** and FIG. **6**, laser diode **902** and light monitor **910** supply a feedback signal to laser power controller **912**. Laser power controller **912** supplies a control signal that turns on specific pins of direct digital driver **600** to supply current to the laser diode. Notice, laser power controller **912** could be incorporated into the digital driver **600** by, for example, using programmable logic of a FPGA.

Controlling Intensity and Power

Using the FPGA and digitally driving the laser, it is possible to vary the current driving the laser instantaneously on a bit by bit basis. Thereby imparting a novel flexibility in driving the laser. For example, APON protocols dictate that the logic 0 light intensity be 0. Controlling the laser at 0 intensity also prevents light from a non-transmitting ONU to collide with an ONU having a grant to transmit. However, laser diodes operate in a non-linear manner at low intensity levels. For example, if the laser light intensity is 0 at 5 milliamps, then the laser light intensity is 0 at 2 milliamps, also. This makes it difficult to measure the power levels required for logic 0 light intensities, because of inefficiencies in the feedback.

Analog drives using bi-stable switches to drive the laser provide two currents. The bi-stable switch provides a first current for the logic 0 intensity, and a second current for the logic 1 intensity. The bi-stable switches rapidly switch the drive current between the 0 level drive and the 1 level drive. However, the analog switch is relatively inflexible. In other words, it is difficulty to change the supplied current at either the 0 or 1 level. Using the direct digital drive, however, it is possible to instantaneously alter the laser's drive current. The variation is not only between the 0 and 1 level, but variations between 0 and 1, such as, for example, 2% intensity, 5% intensity, 75% intensity, or any current between 0 and maximum drive. For example, when attempting to measure the non-linear 0 intensity point, it is possible to drive the laser at a level slightly above 0 intensity level, such as, for example using 15% light intensity. Using the drive current level corresponding to light intensity just above 0, it is possible to extrapolate the correct drive current for zero intensity, or a particular below zero intensity current.

FIG. **7** shows a flowchart **700** exemplary of this procedure. First, during the period when the logic 0 light intensity power requirements are measured, the laser would be supplied sufficient power to drive it at 15% intensity, step **702**. The power requirement would be measured, step **704**. Using the power required to drive the laser at 15%, the power requirement for 0% intensity would be calculated, step **706**. The calculated current would be the current used to subsequently drive the laser to a zero level.

Another benefit of the unique controller it can "under drive" the laser. To under drive the laser means supplying power to the laser slightly below its 0 threshold level. For example, if the 5 milliamp current drives the laser at a 0% intensity light, under driving the laser may be done by supplying 4 milliamps or at least some current less than 5 milliamps. By under driving the laser, the laser could be turned on at a level below its 0 level by a predetermined amount. Turning the laser on below the 0 level essentially eliminates any risk of accidentally emitting light from the laser. Thus, the laser could be under driven prior to its designated transmission time. By under driving the laser, the laser has at least partially charged the photons in the lasing cavity. Thus, less time will be required to actually increase the photon density the remaining amount to the lasing threshold density and actually turn on the laser.

FIG. **11** is a diagrammatic representation of useful light intensity to drive current showing the above described control scheme. Similar to FIG. **10**, FIG. **11** represents the transmission of an exemplary cell of information **1102**. Cell **1102***a* represents drive current for exemplary cell **1102** and cell **1102***b* represents light intensity for exemplary cell **1102**. As shown, cell **1102***a* can be considered in discrete parts **1104***a* and **1104***b*. Part **1104***a* is the drive current necessary for the transmission of light having an intensity of logic 1s and 0s for the transmission of cell information. Part **1104***b* is the drive current for the transmission of light having an intensity of logic 0 to allow for a zero level measurement. (A similar period exists for monitoring the logic 1 level, not shown). The duration and timing of part **1104***b* is generally controlled by the associated transmission protocols. Similarly, light intensity shown by cell **1102***b* over the course of cell **1102** transitions between the high and low drive currents for the laser diode.

As shown in FIG. **11**, non-transmission period **1108** has two parts also, part **1108***a* is a period when no current is supplied to the laser. Part **1108***b* is a pre-drive period. In the pre-drive period, the digital drive is calibrated to supply a current sufficiently below the 0 logic level current. This allows the photons in the lasing cavity to be partially charged prior to when the laser receives the grant to transmit the cell **1102**. Because the laser can be pre-charged for a predetermined time prior to receiving the transmission grant, the first light pulse of data **1106** can be used. In contrast, prior art power sources required at least the first pulse **1006** to be wasted because the laser had to ramp up to operating conditions.

Further, as mentioned above, measuring the current necessary to drive the laser at a 0% light intensity is difficult due to the non-linear nature of lasers below the 0% threshold. Thus, using the digital drive it is possible during part **1104***b* of the cell transmission to measure the current needed to drive the laser at, for example, 15% intensity. This light intensity during part **1104***b* of the cell transmission is shown by part **1110**. Notice while 15% is stated, other percentages could be used, such as 2% light intensity, 5% light intensity 50% light intensity, 78% light intensity, etc. It is possible to measure the drive current **1112** used to produce light intensity **1110** and then calculate the drive current that would be necessary to drive the laser at only just a 0% light intensity. The calculated drive current would be used to send logic 0 signals and to pre-drive the laser at some predetermined current below the logic 0 current.

Implementation of Functionality in FPGA

Referring to FIG. **8**, section **8** of the G.983.1 standard indicates several functionalities for ONU transceivers **800**. FIG. **8** shows a conventional ONU transceiver **800**. Transceiver **800** includes a transmission portion **802** and a receiving portion **804** to send and receive optical signals. Transceiver **800** typically contains a hardware portion **806**, such as conventional synchronization circuitry **808**, switching circuitry **810**, signaling circuitry **812**, and a user interface circuitry **814** and a software portion **816**. Traditionally, a microprocessor is used to implement software-based controls of the G.983.1 standard, such as data verification and security, such as churning. It has been discovered, however, that significant advantages are obtained when the microprocessor based software controls are replaced with field programmable logic 820, a.k.a. a FPGA. Any conventional method can be used to program the programmable logic of the FPGA to perform the functions conventionally performed by the microprocessor-based software. As shown, the FPGA **820** can be a single chip that encompasses the both the conventional hardware (circuits **806**, **808**, **810** and **812**) as well as the conventional software portion **816** normally executed by a microprocessor.

Using the FPGA to provide the software functionality provides several advantages. First, using the FPGA logic allows a single chip (the FPGA chip) to control the PON operation. Using one chip to control the PON reduces costs, power consumption, space, etc. Further, using one chip provides increased reliability.

Using the FPGA also avoids typical parallel efforts between hardware and software development engineering groups (with their well known communication delays, and difficulties with integrating and testing two disparate design parts). Moreover, updates to the hardware and software can be provided in one combined image. Image is a term for an array of data bytes used to program a device, such as a FPGA. Often software is updated in the field by downloading an image, in this case from OLT **102** to ONU **104**. ONU **104** would then use the new image to update itself, without, of course, replacing its memory. Occasionally programmable hardware is updated with a new image in the above fashion. The new hardware often needs software to recognize the new hardware. By using a single FPGA to do both the hardware and software functions, the software and hardware updates can be transmitted using a single image.

Using programmable hardware also provides unique operational advantages. In particular, performing multiple tasks in a microprocessor based software is, in reality, performing a little piece of each task in serial, choosing suitably small pieces to give the illusion that they are happening simultaneously. Implementing the software in the FPGA, however, allows parallel operation using separate logic for each function. Using separate logic paths can be faster. Further, parallel processing in the FPGA has a higher reliability than parallel processing in a software environment. Generally, the FPGA has a lower probability of getting hung up. In other words, because the functions are performed on separate logic paths, there is less chance of one process holding up another, although both still only do one little piece of one thing at a time and if the sequence gets lost the whole machine needs restarting. With separate entities if one gets lost the other processes carry on unaffected, and there is a good chance the lost process will get sorted out again.

Finally, a hardware implementation in CMOS generally uses less power then an equivalent function implemented in a microprocessor based software. The FPGA requires less power because the same functionality can be programmed using fewer gates. Also, gates can be toggled as required, thus less gate charge is moving. Less gate charge means less current and energy. For example, a 16 bit counter in hardware where 16 logic flip-flops hold 16 bits of data in place. They each are toggled only as required to make the count. A general-purpose processor, however, may store 16 bits of data in a 32-bit memory until required. The 32 bits (many of which are unused in this example, then are routed out of memory, through the general purpose logic and back to memory to achieve the same function.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various other changes in the form and details may be made without departing from the spirit and scope of the invention.

I claim:

1. Apparatus for digitally driving a laser with a current in a passive optical network, comprising:

a programmable voltage source;

an output terminal directly connected to the laser to thereby provide a drive current to the laser of a magnitude that is a direct function of the magnitude of a voltage on the output terminal;

the programmable voltage source having a plurality of output pins, each of the output pins selectively having a voltage thereon, and each of the output pins being individually connected to the output terminal through a resistor; and

a controller connected to supply a control signal to the programmable voltage source, the control signal specifying which of the plurality of output pins are to have a voltage thereon, to thus determine the magnitude of a voltage to be applied to the output terminal and the magnitude of a current to be supplied to the laser from the output terminal.

2. Apparatus according to claim **1** wherein the control signal is a digital control signal and wherein the programmable voltage source and the controller are incorporated within a FPGA.

3. Apparatus according to claim **1** wherein the programmable voltage source is selected from the group FPGA, DAC, ASIC, and microchip device.

4. Apparatus according to claim **1** including:

a plurality N of output pins; and

a plurality N of resistors, each resistor having one end connected to a different one of the output pins, and each resistor having an opposite end connected to the output terminal.

5. Apparatus according to claim **1** including:

a light measuring device for measuring a light intensity output from the laser; and

a feedback signal generator connected to receive an input from the light measuring device;

the feedback signal generator having an output connected to the controller to cause the controller to adjust the control signal as a function of a measured light intensity output from the laser.

6. Apparatus according to claim **5** wherein the light measuring device is a photodiode.

7. Apparatus according to claim **5** wherein the programmable voltage source is a FPGA.

8. Apparatus according to claim **8** wherein each of the plurality of output pins has the same voltage thereon.

9. Apparatus according to claim **8** wherein at least one of the plurality of output pins has a different voltage thereon.

10. Apparatus according to claim **1** wherein voltages on the plurality of output pins and resistance values of the plurality of resistors are selected to provide a binary progression of current magnitudes at the output terminal.

11. Apparatus according to claim **1** wherein at least one of the plurality of output pins is connected to the output terminal through a filtering capacitance device or a pulse width modulating device.

12. A method for transmitting a cell of information in an optical network by selectively driving a laser with a current, the method comprising the steps of:

providing a digital drive signal that is a function of the cell of information;

receiving the drive signal at a programmable voltage source;

providing a plurality of output pins for the programmable voltage source, each of the output pins selectively having a voltage thereon that is a function of the drive signal;

providing an output terminal;

individually connecting each of the output pins to the output terminal through an individual resistor;

connecting the output terminal directly to the laser; and

selectively providing a voltage on the output pins of the programmable voltage source as a function of the drive signal such that current supplied to the laser has a magnitude that is a function of the drive signal.

13. The method according to claim **12** further comprising the step of:

measuring an intensity of light output from the laser; and

adjusting the drive signal as a function of the measured light intensity.

14. The method according to claim **12** wherein the step of providing a drive signal comprises the steps of:

providing a first drive signal corresponding to a first light intensity from the laser; and

providing a second drive signal corresponding to a second light intensity from the laser;

the first light intensity corresponding to a logic 1 signal; and

the second light intensity corresponding to a logic 0 signal.

15. The method according to claim **12** wherein the step of selectively providing a voltage on the output pins as a function of the drive signal comprises the steps of:

providing a voltage on a first output pin or a first group of output pins in response to a first drive signal; and

providing a voltage on a second output pin or a second group of output pins in response to a second drive signal.

16. The method according to claim **15** further comprising the steps of:

storing the first drive signal;

storing the second drive signal;

wherein the step of providing the first drive signal utilizes the stored first drive signal; and

wherein the step of providing the second drive signal utilizes the stored second drive signal.

17. The method according to claim **14** further comprising the steps of:

measuring the first and second light intensities from the laser;

adjusting the first drive signal as a function of the measured first light intensity; and

adjusting the second drive signal as a function of the measured second light intensity.

18. The method according to claim **16** further comprising the step of:

measuring the first and second light intensities from the laser;

replacing the stored first drive signal as a function of the measured first light intensity; and

replacing the stored second drive signal as a function of the measured second light intensity.

19. The method according to claim **16** further comprising the step of:

normalizing the stored first and second drive signals.

20. A direct digital drive for a laser in a passive optical network, comprising:

an output terminal directly connected to the laser to thereby provide a drive current to the laser whose magnitude is a function of a current that is provided to the output terminal;

a DAC having a digital input and a plurality of analog outputs, all analog outputs being individually connected to be summed at the output terminal, and at least some of the analog outputs being individual connected to the output terminal through an individual resistor;

a controller connected to transmit a digital laser drive signal to the digital input of the DAC;

the DAC selectively activating certain ones of the analog outputs and providing a summed analog current magnitude to the output terminal as a function of the digital laser drive signal; and

the output terminal providing an analog current magnitude to the laser as a function of the selective activation of certain ones of the analog outputs, so that the laser outputs a light signal at a light intensity that is a direct function of the digital laser drive signal.

21. The direct digital drive according to claim **20** wherein the DAC is selected from the group ASIC silicon, microchips, and programmable logic.

22. The direct digital drive according to claim **20** including:

a light intensity measuring device for measuring a light intensity output from the laser; and

a feedback signal generator responsive to the light measuring device and connected to the controller in a manner to adjust the digital laser drive signal as a function of the measured light intensity.

23. The direct digital drive according to claim **22** wherein the light intensity measuring device is a photodiode.

24. The direct digital drive according to claim **20** wherein the DAC is a FPGA.

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